Technical Assessment of Using Dispersants on Marine Oil Spills in the U.S. Gulf of Mexico and California

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ABSTRACT: *This paper describes two comprehensive technical assessments of potential dispersant use in the Gulf of Mexico Region (GOMR) and Pacific Outer Continental Shelf Region (POCSR). The assessments considered both operational and environmental issues. Spill scenarios currently used for spill response planning or environmental impact assessments were analyzed. Dispersibility of oils and "time-windows" (TWs) for dispersant operations were assessed for GOMR- and POSCR-produced crude oils, as well as for oils imported into California. The TWs were estimated by oil fate modeling. It was found that most of the GOMR-produced oils for which data were available are light and dispersible when fresh. By contrast, only a few of the POCSR produced oils appear to be dispersible. The situation for oils imported into California is more favorable, as over 50% of crude oil volume imported annually is comprised of oils with adequate TWs. Logistic capacities of various dispersant application platforms were analyzed. Net environmental benefit (NEB) of dispersants was determined by analyzing a number of spill scenarios. Impact and NEB were estimated using models of oil fate, trajectory and environmental impact, combined with resource vulnerability databases. In the NEB-GOMR analysis, dispersants offered a clear net environmental benefit in every scenario. The NEB-POCSR analysis yielded similar conclusions, even though the study involved more complex scenarios.*

Introduction

In recent years important advances have been made in dispersants. Spill responders in the U.S. have integrated dispersants into their response arsenal for spills from vessels. However, some areas are at risk from spills from offshore oil production, as well as from vessels (e.g., Gulf of Mexico, Southern California Bight, Alaska North Slope). Beginning in 1999, the U.S. Minerals Management Service sponsored two projects to assess dispersants for treating production-related spills in the Gulf of Mexico and California. The projects emphasized: a) fundamental dispersibility of the local crude oils; b) time windows (TW) for dispersant use under local conditions; c) logistics limits of platforms to deal with typical spills; and d) net environmental benefit (NEB) of using dispersants in different locations. The first project focused on MMS-regulated facilities on the Gulf of Mexico Outer Continental Shelf Region (GOMR)(Figure 1). The second addressed similar issues for MMS facilities in the Pacific Offshore Continental Shelf Region (POCSR)(Figure 2). The scope of the POCSR study was expanded by MMS to include spills of both production-related and imported crude oils in order to support an ongoing reassessment of dispersant policies in California. This paper summarizes these two projects. For details of input, methods and results refer to SL Ross (2000, 2002a)[1].

Dispersibility of Oils

The first task in each study was to assess the probable dispersibility of the oils in question. This can be inferred based on the density and emulsion-forming potential of the oil.

[1] The reports are accessible on the SL Ross website at (http://www.slross.com/disperse/dispersemain.htm) or on the MMS website at (http://www.mms.gov/tarprojects/349.htm)

Density (API gravity). The density, or API gravity, of an oil is sometimes used as an indicator of likely dispersibility (ITOPF 1987 and S.L. Ross 2002b). Oils with high density (low API gravity) tend to be of high viscosity and are generally harder to disperse than less viscous oils.

Tendency of Oils to Weather to Form Water-in Oil Emulsion. The time from the start of the spill to the point when the oil becomes resistant to chemical dispersion due to increased viscosity caused by evaporative loss and emulsification has been defined as the 'time window' (TW) for dispersant operations. TWs can be expected to vary as a function of oil composition and spill and environmental conditions. Ideally, information concerning TWs for oils should be determined in spills or field tests, but this is not usually feasible. For the present study, TWs have been estimated by computer modeling in two ways: First, TWs were determined for all oils for which detailed data were available, considering standard hypothetical batch spills of 1000 barrels and 10,000 barrels. The limiting emulsified oil viscosities for effective dispersion has been considered to be 5,000 cP for relatively rapid dispersion and 20,000 cP for eventual dispersion. Crude oils could then be defined on the basis of general emulsification tendencies: Hi-E (high emulsification tendency and short TW); Av-E (intermediate emulsification tendency and TW); Lo-E (low emulsification tendency and relatively long TW); and so on. Next, a number of representative oils were used to run a series of spill scenarios that were typical of the region. Computer simulations of oil fate and behavior (see SL Ross 2000 and 2002b for details) were conducted to assess the influence of spill conditions on operational dispersibility of spills. Spills of different types and sizes of spills were analyzed. Spill scenarios were developed reflecting realistic production-related spills in the GOMR and oil spills resulting from both production and transportation incidents in the POCSR.

Gulf of Mexico Outer Continental Shelf Region (GOMR) crude oils. The dispersibility of GOMR oils was as follows.

Effect of Density. There are thousands of oils produced for individual wells in the GOMR. The majority of oils are light (average API gravity is about 33^{o} = 0.86 specific gravity), suggesting that most might be amenable to chemical dispersion.

Standard spill scenario modeling. Twenty-eight GOMR oils have been thoroughly analyzed and modeled in previous projects funded by MMS (MMS 1996, 1998, 1999). A summary of the results is presented in Table 1. Modeling of standard scenarios using the 28 oils GOMR oils yielded the following conclusions.

1. Four of the 28 GOMR oils appeared to be highly emulsifiable, with very short TWs (see Table 1). Hereafter these are called Hi-E oils (= highly emulsifiable). They are oils that will emulsify after only 10% or less of the oil volume has evaporated.

2. Twenty-nine percent of these oils are Av-E oils (=average tendency to emulsify). For these, there is a relatively short TW, but still more time is available than with Hi-E oils.

3. The next category is Lo-E oils (= little tendency to emulsify), which make up 32% of total. The TW for Lo-E oils is long, allowing several days to treat the spill.

4. Roughly 25% are No-E oils. These do not emulsify regardless of evaporation. These appear to be ideal candidates for chemical dispersion because of their unlimited TW. They include the diesel fuels used to power offshore rigs and service vessels.

If this small sample is representative of all GOMR oils, then most, 57% appear to be excellent candidates for chemical dispersion and an additional 29% are good candidates.

Representative spill scenario modeling. Batch spills involving diesel oil and No-E oils (scenarios 1a, 1b and 2a, Table 1) appear to be good candidates for chemical dispersion because dispersants will almost certainly be very effective. (Note, however, that there might be significant environmental consequences of dispersing large quantities of diesel fuel, especially in shallow nearshore waters, because diesel fuel contains a large proportion of toxic substituted naphthalenes. Net environmental benefit issues are dealt with below.) Batch spills involving Av-E oil (scenario 2b) are also good candidates for dispersant because: a) the oil is relatively persistent, lasting more than 30 days; and b) it emulsifies only slowly, taking nearly 96 hours to fully emulsify, allowing time for a spraying operation. The spills involving Hi-E oils (scenarios 2c and 3) emulsify quickly to undispersible viscosities within only 10 to 15 hours, allowing only a very brief TW for dispersant response.

Blowouts differ from batch spills in their behavior and logistic challenges. The differences can be illustrated by comparing batch and blowout spills of similar volumes and oil types. A batch spill of Av-E oil (scenario 2b, Table 1) is predicted to require 55 to 96 hours to fully emulsify. This offers a fairly lengthy TW for dispersant response. An above-sea blowout involving the same oil and spill volume (4b) produces a thinner slick, which emulsifies more quickly (10 to 15 hours). The blowout may still be treatable despite the shorter TW, because oil is discharged gradually over a prolonged period, and only a small amount must be treated at any given time. In addition, the TW is long enough that the much of the oil discharged overnight (when dispersant operations are suspended), will be amenable to dispersion on the following day.

In subsea blowout scenarios 6 and 7, the slicks are very thin (0.05 to 0.15mm) and emulsify very quickly, with TWs from 4 to 7 hours. The freshly spilled oil is treatable, but some of the oil released overnight apparently will not be chemically dispersible the following morning.

Pacific Offshore Continental Shelf Region (POCSR) crude oils. The dispersibility of POSCR oils was as follows.

Effect of density. In POCSR, oils from the 22 producing fields are heavy and viscous, with an average API gravity of 20.2°. These values border on the undispersible, suggesting that POCSR oils may be poor candidates for chemical dispersion. Also in POCSR, two to three dozen oils were imported annually in 1999-2001. Alaska North Slope crude oil (ANS), which represents 50% of each annual total, has an API gravity in the dispersible range. On this basis, much of the volume of oil imported into California may be dispersible when fresh.

Standard spill scenario modeling. Of all oils produced in POCSR or imported, only 17 have been characterized well enough to permit modeling of time-dependent spill-related properties. These 17, plus No. 2 fuel oil, were analyzed and categorized in the POCSR study according to emulsion formation tendency.

1. Twelve of the 18 are Hi-E oils, with a very short TW. These include many locally produced oils and most imported oils. Modeling suggests a TW of 4 to 23 hours.
2. The Av-E oil category includes three produced oils and one imported oil, ANS. ANS crude is representative of this class and has TW of 38 to 67 hours.
3. The Lo-E oil category contains only two oils, the locally produced Pitas Point crude oil (a heavy gas condensate) and diesel. There are no imported oils in this category. In the modeling work, these oils appear to disperse naturally before they become resistant to dispersion.

In contrast to the GOMR study, the opportunity for using dispersants effectively on the example oils in the POCSR study appears to be limited. Only 4 of the 13 produced oils studied have lengthy TW. The situation for imported oils is somewhat more promising because, although only one of the four imported oils modeled has a lengthy TW, that oil is ANS, which makes up more than 50% of the volume imported oil. Although the overall proportion of oils with lengthy TW is smaller in the POCSR study than in the GOMR work, there is still some justification for considering dispersants for both production and tanker spills in California.

Representative Scenarios. Trends in the behavior of representative POCSR spills are similar to those of GOMR spills, except that POCSR oils are largely Hi-E or Av-E oils, so they emulsify rapidly. For batch spills from ships in POCSR, spills of 250,000, 10,000 and 3000 barrels of Alaska North Slope and Arab Medium crude oils were analyzed. The two oils differ markedly in their behavior. The ANS scenarios have longer TW (104 to 166 hours) than the Arab Medium crude scenarios (8 to 22 hour) because of the longer delay in onset of emulsification. The TW shrinks as the spill volume decreases for all batch spills.

Logistic Limitations of Some Dispersant Platforms

A detailed analysis of the representative scenarios was performed to assess the capabilities of dispersant spraying platforms to deliver dispersants to realistic spills. Models, assumptions and characteristics of platforms are in SL Ross (2000).

Effect of Emulsification Tendency of Oils. The results of the modeling suggest that certain platforms may be capable of fully dispersing at least the smaller spills, while others cannot. In scenarios involving Hi–E oils, the TWs are very short, allowing time for, at most, one or two sorties by any platforms. At the other end of the spectrum, spills of Lo-E oils have lengthy TWs and commonly dissipate naturally within hours without chemical dispersion. The impact of dispersants is most evident in spills of Av-E oils and these are examined in the next section.

Dispersant Delivery Capacities of Platforms for Batch Spills. The computer-estimated capacities of platforms to deliver dispersants to large batch spills at different distances are shown in Table 4. In principle, based on computer modeling, the ADDS-Pack-equipped C-130, operating over a distance of 30 nautical miles, can complete five sorties per 12-hour day, delivering in excess of 100 cubic metres of dispersant. By comparison, the delivery capacities of the other platforms studied, operating over the same distance were as follows: DC-4, 43% of the C-130 capability, DC-3, 26%; Air Tractor AT-802, 23%; helicopter, 10%; Vessel A, 7% and Vessel D, 58%. Both helicopter and vessel systems can be re-supplied at the spill site and by doing so their performances are improved by factors of 2.7 (helicopter) and 4.5 (vessel).

Net Environmental Benefit of Dispersant Use

Environmental risks and NEB of dispersant use in the GOMR and POCSR were assessed by estimating impacts of dispersed and untreated cases in a number of representative scenarios. The spill launch points are in Figures 1 and 2. Spill impacts was estimated using spill impact assessment models as in SL Ross (2000, 2002b). The scenarios can be divided into three categories. One group includes spills that disperse quickly, within hours by natural means. These pose very modest environmental risks. Chemical dispersion does little to reduce impact and yields little NEB. A second group includes spills that emulsify too quickly for dispersant operations to be mounted. In these too, dispersants offer little potential NEB. In the last group, involving Av-E oils, spills are persistent enough for slicks to reach nearshore areas, but have TWs long enough that they can be fully chemically dispersed. In these spills, dispersants can greatly reduce the risks associated with untreated slicks. As such, they may offer a NEB depending on the risks posed by the chemically dispersed spill. The NEB of dispersants in this latter group was considered in detail, on a scenario-by-scenario.

GOMR Scenarios. The main conclusion from the GOMR study is that if dispersants are used on persistent, but dispersible Av-E oils, there will be a net environmental benefit in almost every case. The reason for this is that the spills from MMS facilities generally originate more than 10 km offshore. When these spills are fully treated near the spill sites (as they must if dispersant is to be effective), the oil is dispersed offshore and environmental risks from dispersed oil are low or lower than those of untreated spills. This was true even in the scenario where the spill site was closest to shore (TX-NS, Figure 1). In this case, there were clear drawbacks from dispersants because the dispersed oil threatened shrimp fishing in a highly productive area at the peak of the fishing season. Nonetheless protections offered by dispersants to amenities, shorelines and wildlife (including endangered species) outweighed their drawbacks. In short, in the GOMR study dispersants offered a NEB in all batch spills on the open coast regardless of spill location or season.

The NEB of dispersants was far greater for a blowout spill than for a batch spill of similar size, based on spills from the TX-NS site. As described above, the batch spill from the TX-NS site caused significant damage, but the dispersed spill caused less damage, so there was a clear NEB of using dispersants. A protracted blowout spill from the same site and involving the same total volume of oil, if left untreated would contaminate a much larger area and cause far greater damage than the untreated batch spill. On the other hand, if this blowout were treated with dispersants the damage would be no greater than with the dispersant-treated batch spill. As a consequence, there was a clear NEB from dispersants in the blowout scenario, and the NEB was greater than in the corresponding batch spill scenario.

California Scenarios. Dispersants offered a NEB in all three POCSR scenarios. The reason is that, as in the GOMR study, the POCSR launch sites were offshore where chemical dispersion posed limited risk. The scenario off San Miguel Island (Figure 1, SMI-BS) was the simplest of those considered here. The NEB of dispersants was clear because the untreated spill threatened very significant damage to important wildlife on San Miguel Island. On the other hand, chemical dispersion posed few, if any environmental risks because; a) chemical dispersion occurred well offshore; and b) surface currents kept the dispersed oil offshore, away from nearshore targets.

The Santa Barbara Channel batch spill scenario (Figure 1, SBC-BS) was more complex than the SMI-BS because it occurred close to shore and some dispersed oil was carried into shallow nearshore waters. However, the NEB in this case still favored dispersants. The blowout scenario involving Platform Gail (Figure 1, PG-BO) addressed two complicating factors: a) the complexity arising from a blowout spill lasting many days; and b) the problem of a dispersant operation that is less than 100% efficient. Despite these additional complications, dispersants offer a clear NEB although this may not be true in all scenarios.

Conclusions

Hundreds of oils are produced in GOMR and twenty-two in POCSR. Most GOMR oils are light and dispersible. Over 85 percent appear to have time windows (TW) of a few days or longer. By contrast, most POCSR oils are heavy, bordering on the undispersible range. The potential for using dispersants on oils imported into the POCSR is promising because a sizable proportion is dispersible when fresh.

The spill and response conditions of scenarios in both areas were similar. The maximum theoretical dispersant delivery capacities of spraying platforms were estimated using simple spreadsheet models. The analyses suggested that the maximum theoretical delivery capacity of the largest platform, the C-130/ADDS Pack was approximately 104 m^3 of dispersant sprayed per 12-hour day at an operating distance of 30 nautical miles. Other platforms performed as follows relative to the Lockheed C-130: DC-4, 43% times the C-130, DC-3, 26%; Air Tractor AT-802, 23%; helicopter, 10%; and vessels, 7 to 58%.

The analysis of net environmental benefits (NEB) showed that for the spill scenarios considered, dispersants yielded a clear NEB in all cases. In both studies, a number of locally important spill scenarios were considered involving different spill types, sizes and launch points. In the GOMR study, environmental gains derived from dispersant use were greatest in the scenarios involving spills of manageable size, with persistent, but dispersible oils. In these scenarios, dispersants appeared to offer a clear NEB regardless of the launch site, spill type and season of the spill. The result was due to a number of factors, including the fact that the launch points of these spills were all at least 10 km offshore. A similar trend was observed in the analyses of POCSR scenarios, in that NEBs in spills on the open coast generally favoring dispersant use in both batch and blowout spills. Overall, it is reasonable to conclude that for most marine spills of this size in these areas, effective chemical dispersion of spills would generally offer a net environmental benefit. This is certainly true for offshore spills and appears to be true for spills in shallower, nearshore waters, as well, with some possible exceptions.

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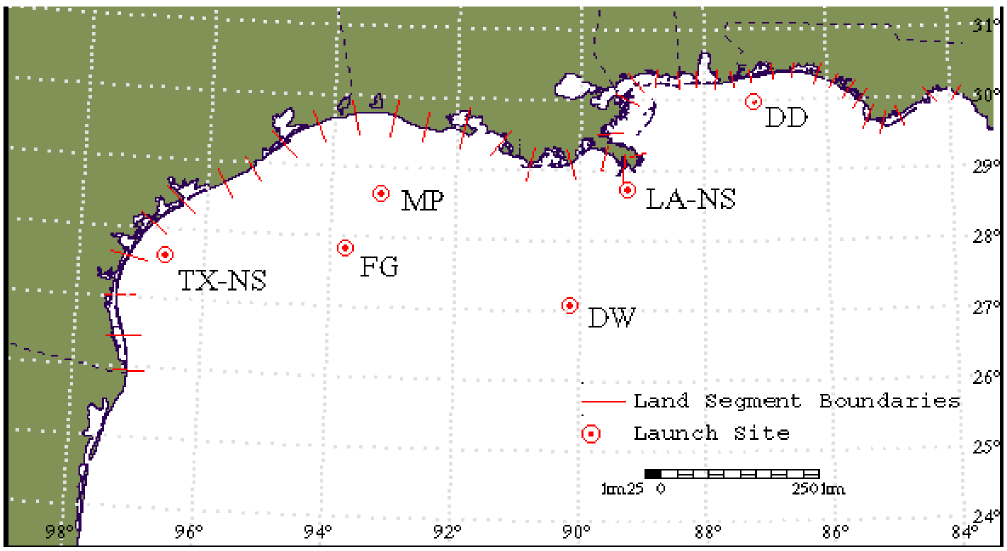

Figure 1 Study Area for Gulf of Mexico Study, Showing Spill Locations

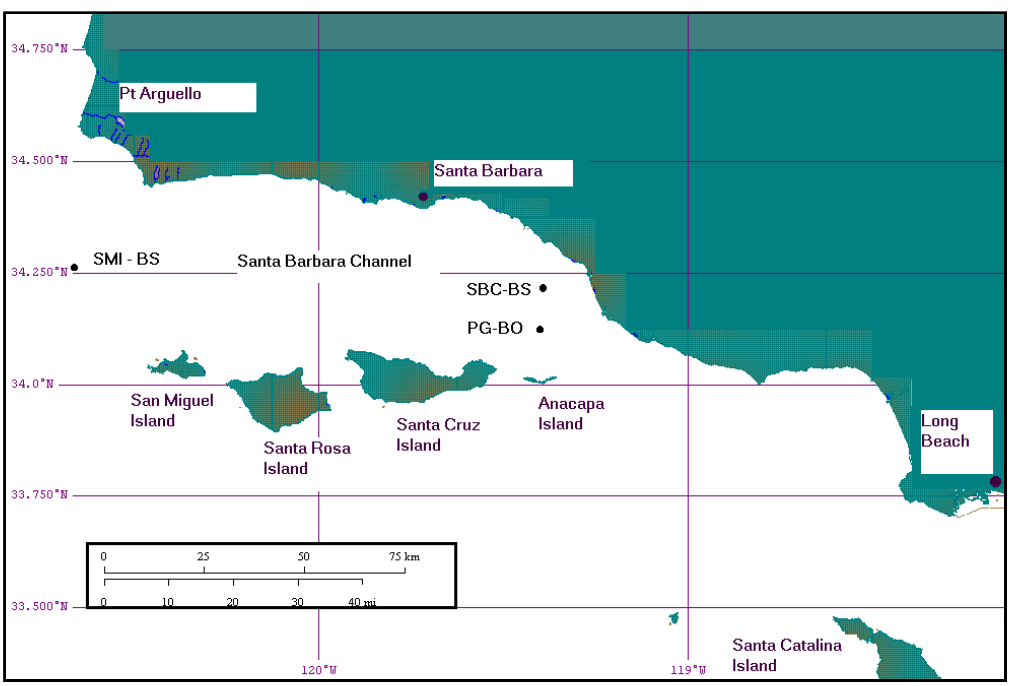

Figure 2 Study Area for California Study, Showing Spill Locations

Table 1 Spill Scenario Modeling Result Summary

	Spill Scenario															
Identifier	1a	1b	2a	2b	2c	3	4a	4b	5a	5b	6a	6b	6c	7a	7b	7c
Spill Info																
Emulsification Tendency	N	N	L	A	H	Hi	L	A	Hi	Av	A	A	A	Av	Av	Av
Volume Spilled (bbl)	2000	20,000	20,000	20,000	20,000	100,000	20,000	20,000	1,4000,000	1,4000,000	20,000	20,000	20,000	100,000	100,000	100,000
Discharge Rate (BOPD)	Batch	batch	batch	batch	batch	batch	5000	5000	100,000	100,000	5000	5000	5000	7200	7200	7200
Viscosity (cP)																
Time to Visc.>5000 cP (hr)	-	-	-	55	5	5	-	10	2.3	22	4	3.5	2.5	4.3	4.0	2.9
Time to Visc.>20000 cP (hr)	-	-	-	96	12	15	-	15	5.2	36	6	5.5	4.3	7	6.2	4.9
Slick Thicknesses (mm)																
Time to Loss of Slick (hr)	42	119	113	>720	>720	>720	15	>720	>720	>720	414	306	111	576	432	177
Time to < .05 mm (hr)	40	112	110	290	>720	>720	12	>720	>720	>720	24	27	36	30	33	45
Initial Thickness	20	20	20	20	20	20	0.65	0.80	7.2	8.4	0.12	0.09	0.05	0.15	0.12	0.067
At 6 Hours	2.0	4.1	4.6	6.8	11	13.8	0.23	0.40	4.0	1.9	0.06	0.047	0.024	0.082	0.063	0.032
At 12 Hours	1.25	3.0	3.4	5.1	10	13.0	0.1	0.35	3.6	1.3	0.057	0.045	0.022	0.077	0.060	0.030
At 48 Hours	-	1.1	1.4	2.6	8.2	11.2	0.1	0.31	2.5	0.9	0.050	0.038	0.017	0.068	0.050	0.024
When Viscosity at 5000 cP	-	-	-	2.5	11	13.0	-	0.36	5.0	1.0	0.063	0.049	0.025	0.084	0.065	0.034
When Viscosity at 20000 cP	-	-	-	2.4	10	12.7	-	0.34	4.1	0.95	0.061	0.047	0.024	0.08	0.063	0.032
Slick Widths (m)																
Initial Width	140	450	450	450	450	1005	37	36	66	66	300	373	677	340	422	765
At 6 Hours	420	890	820	735	550	1104	45	43	86	133	300	373	677	340	422	765
At 12 Hours	480	990	915	825	566	1118	48	44	89	150	300	373	677	340	422	765
At 48 Hours	-	1150	1090	1003	600	1166	-	46	90	165	300	373	677	340	422	765
At Loss of Slick or 720 hrs	550	1180	1136	1063	730	1386	49	51	90	180	300	373	677	340	422	765
Naturally dispersed Oil (top 10 metres)																
Time when < 5ppm (hr)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time when < 1 ppm (hr)	54	138	140	66	-	-	-	-	-	-	-	-	-	4	4	-
Time when < 0.1 ppm (hr)	153	396	396	210	15	33	9	5	-	39	18	18	24	21	23	30
Peak Concentration (ppm)	2.86	4.6	3.8	2.4	0.3	0.3	0.27	0.2	0.04	0.65	0.9	0.94	0.75	1.08	1.08	0.91
Time Peak Reached (hr)	12	21	21	18	3	3	3	3	1.3	6	2.8	2.5	2.6	3	3	2.9

Table 2 Spill Scenario Modeling Result Summary: Local Production Facilities

	Spill Scenario															
Identifier	1	2	3	4a	4b	5a	5b	6a	6b	7	8	9	10	11	12a	12b
Spill Information																
Emulsification Tendency	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi
Volume Spilled (bbl)	32100	32100	2217	29190	29190	29190	29190	500	500	150000	150000	292	26460	26460	2068	131
Discharge Rate (BOPD)	1070	1070	batch	973	973	973	973	Batch	Batch	5000	5000	batch	882	882	Batch	batch
Viscosity (cP)																
Time to Visc.>5000 cP (hr)	0.0	0.0	1.8	0.0	-	0.0	2.0	0.17	4.7	0	0	0.17	-	4.6	7.0	5.6
Time to Visc.>20000 cP(hr)	0.01	0.0	3.1	0.01	-	0.0	3.5	1.0	22	0.01	0	1.0	-	8.9	12.4	9.6
Time to Loss of Slick (hr)	>720	>720	>720	216	0.16	>720	>720	>720	141	>720	>720	>720	0	>720	>720	>720
Time to < .05 mm (hr)	0	0	>720	0	0	1.0	>720	-	140	0	>720	>720	0	>720	>720	>720
Initial Slick Thickness	0.015	0.238	20	0.014	0.014	0.213	0.184	20	20	0.027	0.77	20	0.006	0.33	20	20
Thickness at 6 Hours	0.012	0.212	10.5	0.012	0	0.189	0.147	10.2	4.1	0.0222	0.71	8.9	0	0.26	6.4	2.8
Thickness at 12 Hours	0.012	0.208	9.6	0.011	0	0.185	.0142	9.3	3.6	0.0219	0.70	8.1	0	0.24	5.7	2.5
Thickness at 48 Hours	0.011	0.2	7.6	0.011	0	0.179	0.134	7.6	2.3	0.0206	0.67	6.6	0	0.23	4.6	2.1
Thickness when viscosity at 5000 cP	0.015	-	12.3	0.014	-	-	0.156	17.6	4.3	0.027	-	16.7	-	0.27	2.9	
Thickness when viscosity at 20000 cP	0.014	0.238	11.4	0.014	-	-	0.151	13.1	3.1	0.020	-	11.9	-	0.25	5.7	2.6
Initial slick width	527	28	150	504	504	28.5	30.0	71	71	1357	40	54	1682	22	145	36
Width at 6 Hours	527	28	200	504	0	28.5	30.0	97	143	1357	40	79	1682	23	245	91
Width at 12 Hours	527	28	207	504	0	28.5	30.0	100	149	1357	40	81	1682	24	256	95
Width at 48 Hours	527	28	226	504	0	28.5	30.0	107	164	1357	40	86	1682	25	274	98
Width at Loss of Slick or 720 hrs	527	28	259	504	0	28.5	30.0	107	171	1357	40	86	1682	25	279	98
Naturally Dispersed Oil (top 10 meters)																
Time when < 5ppm (hr)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time when < 1 ppm (hr)	-	-	-	-	0.16	-	-	-	-	-	-	-	-	-	-	-
Time when < 0.1 ppm (hr)	-	-	-	-	12	-	-	-	12	-	-	-	24	-	-	-
Peak Concentration (ppm)	.00085	0.00084	0.0318	0.00083	1.05	0.00094	0.00865	0.0033	0.3	0.0008	0.0007	0.003	0.56	0.0058	0.07	0.04
Time Peak Reached (hr)	0.8	0.4	1.82	0.8	0.16	0.24	3.5	1.0	1.0	0.06	1.0	1.0	0.0	2.7	1.0	1.0

Table 3 Spill Scenario Modeling Result Summary: Vessel Spills

	Spill Scenario															
Identifier	13a	13b	14a	14b	15a	15b	15c	16a	16b	16c	17a	17b	17c	18a	18b	18c
Spill Information																
Emulsification Tendency	Av	Hi	Av	Hi	Av	Hi	No	Av	Hi	No	Av	Hi	No	Av	Hi	No
Volume Spilled (bbl)	250 k	250 k	250 k	250 k	10 k	10 k	10 k	10 k	10 k	10 k	3000	3000	3000	3000	3000	3000
Discharge Rate (BOPD)	batch	batch	batch	batch	batch	batch	batch	batch	batch	Batch	batch	batch	batch	batch	batch	batch
Time to Visc.>5000 cP (hr)	166	22	104	8	90	19	-	56	7	-	74	17	208	45	6	-
Time to Visc.>20000 cP (hr)	188	120	107	87	112	63	-	59	51	-	91	48	-	48	36	-
Time to Loss of Slick (hr)	>720	>720	>720	425	665	375	560	360	155	97	535	273	208	272	106	74
Time to < .05 mm (hr)	>720	>720	>720	420	650	375	255	350	150	90	520	271	204	270	105	73
Initial Thickness	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Thickness at 6 Hours	12.2	13.1	13.1	14.5	6.0	6.8	4.1	6.9	8.9	4.2	4.2	4.8	2.8	7.9	6.5	2.8
Thickness at 12 Hours	10.3	11.8	11.2	13.7	4.7	5.9	3.1	5.3	7.9	3.0	3.2	4.1	2.1	3.7	5.8	2.0
Thickness at 48 Hours	6.5	10.0	7.3	11.4	2.7	4.6	1.7	3.0	5.6	1.3	1.8	3.2	1.2	2.1	3.5	0.7
Thickness when viscosity at 5000 cP	4.1	10.9	5.4	14.1	2.0	5.4	-	2.8	8.7	-	1.53	3.9	0.025	2.1	6.4	-
Thickness when viscosity at 20000 cP	4.0	8.6	5.4	10.1	1.9	4.4	-	2.7	5.5	-	1.49	3.2	-	2.0	3.9	-
Initial Width	1457	1457	1457	1457	318	318	318	318	318	318	174	174	174	174	174	174
Width at 6 Hours	1716	1663	1654	1566	527	496	646	492	433	624	342	320	421	318	275	405
Width at 12 Hours	1846	1714	1760	1586	590	523	716	549	447	686	385	338	464	357	285	442
Width at 48 Hours	2272	1794	2081	1655	743	561	841	686	487	781	485	362	539	441	310	495
Width at loss of slick or 720 hrs	2769	2079	2411	1829	847	615	927	722	515	797	531	386	582	452	318	499
Time when < 5ppm (hr)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time when < 1 ppm (hr)	-	-	120	108	-	-	-	-	-	108	-	-	-	-	-	-
Time when < 0.1 ppm (hr)	540	>720	>720	>720	665	48	260	216	300	288	48	17	108	96	170	168
Peak Concentration (ppm)	0.7	0.3	1.7	1.0	0.35	1.2	0.94	0.85	0.5	4.3	0.27	0.16	0.75	0.68	0.42	3.5
Time Peak Reached (hr)	24	12	24	84	12	6	12	6	36	6	6	6	6	6	6.4	6

Table 4 Computed Dispersant Spraying Capacity of Platforms at a Distance [a]

Platform	Operating Distance n. mi.	Number of sorties per day	Payload, m^3	Volume of dispersant sprayed per day, m^3	Estimated volume of oil dispersed per day[b], m^3
C-130/ADDS Pack (c)	30	5	20.8	104	2080
	100	4	20.8	83.2	1664
	300	3	20.8	62.4	1248
DC-4 (d)	30	6	7.5	45.5	900
	100	4	7.5	30	600
	300	3	7.5	22.5	450
DC-3 (e)	30	6	4.6	27.6	552
	100	4	4.6	18.4	372
	300	3	4.6	13.8	276
AT-802	30	8	3.0	24	480
	100	5	3.0	15	300
Helicopter	1	30	0.9	27	540
	30	11	0.9	9.9	198
Vessel A	1	9	3.4	30.6	612
	30	2	3.4	6.8	136
	100	1	3.4	3.4	68
Vessel D	30	1	75.7	60.6	1211
	100	1	75.7	60.6	1211
	300	0.5	75.7	30.3	605.5

1. Based on simulated response a batch spill of 3180 m^3 (20,000 bbl.
2. Assumes 20 volumes of oil are dispersed per 1 volume of dispersant sprayed.
3. ADDS Pack specifications as per Biegert Aviation: Maximum Reservoir Capacity = 5500 gal. (20.8 m^3.), Recommended Capacity = 5000 gal. (18.9 m^3.).
4. Values reported in literature for payload of DC-4 range from 2000 to 2500 gallons (7.5 to 9.5 m^3.). Value used here is 2000 gal. (ASI, no date)
5. Values in literature for payload of DC-3 range from 1000 to 1200 gal. Value used here is 1200 gal., as per (ASI, no date)